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Navigation and Applied Sciences

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An Integrated Approach to Electronic Navigation

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ABSTRACT
While the Global Positioning System (GPS) is and will continue to be an excellent navigation system, it is neither flawless nor is it the only system employed in the navigation of today's seagoing warfighters. The modern warfighter must operate with dominant maneuverability, precision engagement capability, full-dimensional protection, and focused logistics. To meet these requirements, an integration of independent, self-contained, self-initiated, and externally referenced systems must be realized. The Navigation Sensor System Interface (NAVSSI) AN/SSN-6 (V) provides this capability through the real-time collection, processing, and distribution of accurate and reliable positioning, navigation, and timing (PNT) data from varied shipboard sensors and systems. NAVSSI adds to this an electronic navigation capability that provides the ship navigation team with route planning, route monitoring, and safety of navigation capabilities.

INTRODUCTION

The Navigation Sensor System Interface (NAVSSI) integrates inputs from various shipboard navigation sensor systems, distributes the integrated navigation solution to shipboard users, and provides a dedicated workstation to the ship's navigator. NAVSSI uses an open systems architecture, government off-the-shelf (GOTS) software, and commercial off-the-shelf (COTS) hardware [1].

NAVSSI is an Evolutionary Acquisition (EA) program that is entering its fourth phase: the development of Block 3 hardware and software. The new Block 3 configuration is being developed to expand the number of sensor and user systems supported. Block 3 also incorporates a Global Positioning System (GPS) Joint Program Office approved embedded GPS receiver directly into NAVSSI, refines its integrated navigation solution algorithms, and further expands the navigation tools available to the ship's navigation team.

The NAVSSI system is actually an integration of subsystems. The Real-Time Subsystem (RTS), which collects, processes, and distributes the positioning, navigation, and timing (PNT) data, uses a set of navigation source integration algorithms to blend input data from sensors such as GPS and Inertial Navigation Systems (INS) to produce a highly accurate and robust navigation solution. When required, this solution is referenced to the ownship's reference point (OSRP).

The Display Control Subsystem (DCS) provides the operator interface to the RTS. It also contains the electronic charting and navigation capabilities as well as a radar interface and chart product distribution capability. The charting software used is the U.S. Coast Guard developed Command Display and Control Integrated Navigation System (COMDAC INS). The DCS and COMDAC INS software packages are built on the Defense Information Infrastructure Common Operating Environment (DII COE) and together will enable NAVSSI to lead the way to Electronic Chart Display Information System–Navy (ECDIS–N) compliance.

The DCS can display ownship's navigation sensor information, log navigation fix data, use the navigation toolkit, display digital nautical charts and radar contacts, and control the RTS(s). The RTS accepts and integrates data from both external navigation sensor systems and the embedded GPS receiver cards. The RTS distributes real-time navigation data and precise time to shipboard user systems and communication systems.

The DCS communicates with each RTS via a local-area network (LAN). Depending on the particular installation this may be an independent subsystem LAN or an existing shipboard LAN. Many, but not all, installations of NAVSSI Block 3 will include two RTSs. On a dual RTS installation, two RTSs will exchange data via a reflective memory link.

Other system components are the Bridge Workstation (BWS) and NAVSSI Remote Station (NRS), which are the remote displays for the DCS operator. The NAVSSI BWS and NRS have full control and display capabilities to ship's force on the bridge.

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The following sections describe the requirements for system performance and the operational characteristics of the NAVSSI Block 3 System.

REAL-TIME SUBSYSTEM (RTS)

The NAVSSI RTS receives navigation data from multiple sensors and systems and provides real-time output of an integrated navigation solution to multiple user systems. The NAVSSI RTS(s) accepts and processes data in a variety of formats as listed in Table 1.

Data Integrity Checking

NAVSSI continuously monitors the data inputs from each source listed in Table 1 to ensure data integrity. Integrity checking consists of, but is not limited to, ensuring proper reception of data over the physical medium connecting the source to NAVSSI. Incomplete messages, messages with checksum errors, etc., are processed as identified in the appropriate interface design specification (IDS). As required, NAVSSI posts visible alerts to the operator.

TABLE 1. Summary of Block 3 data inputs.

System	Message Rate (Hz)[Note 1]	Data Received
Redundant RTS	50[Note 2]	All Sensor Data
DCS	Variable	All Sensor Data, Control, Config, Lever Arms, etc.
AN/SPS 73	1	Scanned Radar Images/Contacts
AN/WRN-6 IP	1	PVT, almanac, status
AN/WRN-6 ntds	1	PVT, status
AN/WSN-5 Ch A	4.07	PVT, $speed_w$, performance
AN/WSN-5 Ch B	8.14 or 16.28	PVT, attitude, $speed_w$, performance
AN/WSN-7 GPS/010	4	PVT, attitude, $speed_w$, performance
AN/WSN-7 Superchannel	50[Note 2]	PVT, attitude, rate $speed_w$, performance
BFTT	1	Training Data
Speed $Log_{digital}$	8	$Speed_w$
DMS/FODMS	10[Note 2]	INS, fathometer, wind, propulsion
DSVL	8	$Speed_w$ or $speed_g$
EM Log	Continuous	$Speed_W$
Fluxgate compass	1	Heading
FOAL receiver	Continuous	RF Input
GVRC	1	PVT, status, almanac
Gyrocompass	Continuous	Synchro heading
ICAN	Wind at 10 Std Msg at 50	Wind speed and direction, std msg
IP-1747/WSN-7	0.125	WSN-7 Control
MK 38 AEGIS Clock Converter	1024	Aegis Combat System Time
MK 39 AEGIS Clock Converter	1024	Aegis Combat System Time
Moriah (NDWMIS)	10	True wind speed and direction
SWAN	50	Std msgs
LPD 17 Wind	10	Wind speed and direction
UQN-4/4A	1	$Depth_{keel}$

[Note 1] Data rates are approximate.
[Note 2] Multiple messages, highest rate given.

Message level validity checking is conducted based on source validity indicators transmitted with the data if the appropriate IDS provides for such indicators. Sources indicating that their data are invalid are not used by NAVSSI until the data are again marked valid by the source.

NAVSSI provides navigation data validity monitoring, consisting of continuous monitoring of the time evolution of each position source's error characteristics. If estimates in the source's error consistently fall outside of the source's statistical performance bounds, the source is marked as invalid. The automatic source integration algorithm does not use these data, and NAVSSI posts a visible alert to the operator. If a NAVSSI operator manually selects a source that is out of its performance bounds, NAVSSI displays a warning message to the operator.

Navigation Source Integration

NAVSSI provides navigation source integration algorithms that blend the input data received from GPS with available INS data to produce a highly accurate and robust navigation solution. The algorithms written to perform navigation source integration take into account the error characteristics associated with each navigation sensor system and will meet the accuracy requirements specified in Table 2. Each RTS resolves navigation position information from each sensor to the same single shipboard reference point. The reference point for this integrated solution is the OSRP. User systems receive data based on the integrated OSRP solution, excepting those systems for which the IDS states that the data shall reflect a specific data source reference point.

The navigation source integration algorithms operate automatically or manually.

Automatic Source Selection Mode

In Automatic Mode, the RTS(s) provides navigation data from the data sources selected by the navigation source integration algorithms to the DCS and external user systems. The Automatic Mode is the default mode.

The navigation source integration algorithms estimate the accuracy of the data being output by NAVSSI. This accuracy estimate is based on the known nominal error characteristics of the available sensor systems, a comparison of the available data and the maintenance of long-term sensor accuracy data. Some user systems are sent the accuracy estimation data as part of their data message. For other user systems, these data are used to determine the setting of validity bits.

The source integration algorithms enable NAVSSI to provide appropriately referenced latitude and longitude accurate to within 12 m (two dimensions, one sigma) under non-casualty conditions. This accuracy requirement is significantly more stringent than the current requirements for INSs and is one of the primary drivers for the redesign of the NAVSSI Block 2 source integration routines into source integration routines in Block 3. The accuracy requirement is based on a root-sum-square of all known error components, including the worst-case latency-related error for each of the interfaces.

NAVSSI integrates velocity input from the various sensors to maintain a real-time estimate of accurate velocity. A maximum ship speed of 40 knots is assumed.

The source integration algorithms enable NAVSSI to provide attitude data from the best available attitude source. On ships that have INSs, NAVSSI tracks the accuracy of the INSs and provides the users with attitude data from the chosen INS. As seen in Table 2, attitude latency is critical for many user systems because the error caused by data latency can quickly exceed the error budget. Therefore, for certain user systems, it is necessary to schedule data output messages to coincide with the receipt of fresh data from the appropriate sensor in order to meet the requirements given in Table 2.

Manual Source Selection Mode

The operator can override the automatic source selection algorithms for the data displayed on the DCS and the data sent to external users. The operator is prompted to choose one or all of the following sources: position data source, velocity data source, attitude data source, or time data source.

When in manual override, the data sent to the DCS, the INS, and the other external users are taken from the manually chosen sources for data. If the operator does not manually choose a source for a particular type of data, those data continue to be provided via the navigation source integration algorithms. In addition, the NAVSSI operator can manually override the INS integration algorithms and choose the best INS.

If there is a loss of communication with a manually chosen source or if the data from that source are marked as invalid, the following are performed:

- the RTS(s) sends an alert message to the DCS operator;
- if position data were manually selected, the RTS(s) estimates position from the last valid message from the manually selected source and provides these data to the DCS and/or users;
- if velocity data were manually selected, the RTS(s) marks the velocity data being sent to the DCS and/or user systems as invalid;
- if attitude data were manually selected, the RTS(s) marks the attitude data being sent to the DCS and/or user systems as invalid;
- if the time source was manually selected, the RTS(s) maintains the last offset calculated from the chosen time source and uses the microprocessor clock to continue to update time.

Position Data Referencing

The lever arms to correct navigation data from each sensor system to OSRP are entered into the RTS(s) system configuration files via the DCS by the installing activity. Once entered, these lever arm data are maintained in non-volatile storage as part of the ship's NAVSSI system configuration files so that the RTS(s) automatically performs OSRP corrections. Thus, all user systems receive position data referenced to OSRP unless the IDS for that system interface specifically designates that a particular sensor's uncorrected data be used for the position data for that system.

Lever arm data from the following systems (if installed) are provided to the RTSs so that the RTSs perform the corrections needed to reference all position data to OSRP: GPS antenna No. 1, GPS antenna No. 2, INS No. 1, and INS No. 2.

GPS reset data sent to the ship's Inertial Navigation Systems are referenced to OSRP. This is done in order to make the system work equally well with AN/WRN-6 or the dual antenna GPS Versa Modular European Receiver Card (GVRC).

If attitude data are not available from the INS, NAVSSI uses the following estimates to complete its OSRP lever arm corrections:

- Heading = TAN-1 (VE/VN) for positive Velocity East (VE) and VN
  = 180° + TAN-1 (VE/VN) for negative Velocity North (VN)
  = 360° + TAN-1 (VE/VN) for negative VE and positive VN
- Roll = 0°
- Pitch = 0°

INS Accuracy Estimation

In most of the Block 3 configurations, NAVSSI communicates with an installed INS. Depending on the installation, this INS can be the Standard Shipboard Inertial Navigation System (AN/WSN-5) or the Ring Laser Gyro Navigator (RLGN or AN/WSN-7).

Each RTS normally communicates directly with only one INS, but will have access to the data from the other INS in dual RTS/INS installations via a reflective memory link with the second RTS. In support of the sensor integration algorithms and as an aid to the ship's navigation team, each RTS independently and continuously evaluates the accuracy of both INSs. This independent assessment of INS accuracy uses GPS data (when available) and enables NAVSSI to estimate INS accuracy both in terms of absolute accuracy and accuracy relative to the other INS. Thus, these routines enable NAVSSI to choose INS data from the more accurate INS. However, the accuracy algorithms will include a minimum 10% allowance for hysteresis. This will prevent NAVSSI from repeatedly switching back and forth between the two INSs when both have relatively similar performance characteristics. These accuracy estimation routines are a significant improvement over the Block 2 INS assessment algorithms, which simply used the accuracy bits provided by each INS and did not attempt to make any independent assessment of INS accuracy.

The RTS(s) can receive and respond to a manual selection of best INS from the DCS.

Estimated Position Processing

The RTS(s) calculates Estimated Position (EP) based on discrete position fixes, best available heading source, and best available speed source. The RTS(s) can also use manually entered course and speed to calculate EP. EP data are provided to the source integration algorithms for consideration as a candidate for source integration and to the DCS for display. However, EP is not used as source data unless manually selected or as the result of multiple sensor failures.

RTS Output Data

The NAVSSI RTS outputs navigation and time data in a variety of formats. Table 2 summarizes the data output requirements and lists interface criticality requirements for maintaining communications in the event of single and multiple point failures.

Output Data Time Tagging

Time information within output data messages is accurate to within 200 msec (two sigma) root-sum-squared with any timing inaccuracy of the sensor data when the output message structure provides sufficient resolution to support this accuracy. In case of a loss of GPS input, NAVSSI is able to maintain time accurate to 1 msec for 1 day and accurate to 10 msec for 14 days.

Precise Time Distribution

The NAVSSI RTS(s) provides accurate time to user systems by means of Have-Quick, Binary Coded Decimal (BCD) time code, Inter-Range Instrumentation Group (IRIG-B) time codes, 1 pulse per second (1 PPS), and 10 pulse per second (10 PPS). The Have-Quick, BCD time code, and 1-PPS signals meet the standards specified in ICD-GPS-060. The IRIG-B time conforms to the standards set forth in IRIG Standard 200-98. The 10-PPS signal, implemented in the NAVSSI Precise Time Unit has all of the characteristics of the 1 PPS signal except that it is at 10 times the rate. Table 2 identifies the accuracy of the time data required by the various user systems. All requirements are in terms of a two-sigma level of accuracy.

TABLE 2. Block 3 data output summary.

System	Message Rate (Hertz)	Position Accuracy (meters)	Attitude Latency (msec)	Time Accuracy (msec)
ACDS Block 0	8	100	0	100
KSQ-1	1	100	N/A	1000
SMQ-11	50	10	20	1000
SPS-73	4 or 1	16	N/A	100
SQS-53d	1	100	N/A	100
SRC-54 Singars	1	N/A	N/A	1
TPX-42	8	10	50	100
WRN-6	4	N/A	100	N/A
WSN-5	1	100	N/A	1
WSN-7	1	100	N/A	1
ATWCS	Multiple	N/A	N/A	N/A
BFTT	1	0	1000	0.1
BGPHES	1	100	N/A	N/A
CADRT	1	N/A	N/A	N/A
CEC	50 [Note 1]	20	10	0.001
CDL-N	8	100	60	100
COBLU	1	100	N/A	N/A
Combat DF	1	100	N/A	N/A
DCS	1	N/A	N/A	N/A
DBB	1	100	N/A	1000
DSVL	8	N/A	250	125
ERGM	1	20	N/A	10

(Table 2 is continued on the following page.)

[Note 1] Multiple messages, highest rate given.

Output NAVSSI Standard Messages

NAVSSI Standard Messages have been created to facilitate future design efforts for use of a wide variety of potential user systems. The Standard Message content is independent of the hardware chosen for any particular interface, allowing this message to be sent at different rates and over a wide variety of point-to-point and LAN interfaces. NAVSSI Navigation Message is a generic sub-message format designed to meet the requirements of various navigation user systems. It includes basic navigation data and time data. Other sub-messages include True Wind, Apparent Wind, Magnetic Variation, Own-Ship Distance, and Navigation Sensor.

Expansion Port Capability

NAVSSI Block 3 has the capability of supporting at least six new users without any software or hardware system modifications. To meet this goal, each Block 3 RTS hardware suite is designed with expansion ports, of which at least two output ports will be Electronic Industries Association (EIA) Standard RS-422 and at least two ports will be MIL-STD-1397 Rev C Type E (Low Level Serial). Electronic cards supporting the expansion ports need not be actually installed, but the internal cabling and backplate connectors do need to be fully prepared. NAVSSI Expansion Ports transmit one of three messages: the accuracy of the data are 25 m for position, 100 msec for time, and 100 msec for attitude latency. For RS-422 interface, the transmission rate is selectable between 1 or 4 Hz. For NTDS-E interface, the transmission rate is selectable as 1, 4, 8, 16, or 50 Hz. The WRN-6 IP message (or Time Mark Data Message), defined in ICD-GPS-150, has a C4 criticality. The accuracy of the data for position is 25 m and 1 sec for time. The data are transmitted at a rate of 1 Hz over RS-422 interface. The NMEA 0183 message, defined in National Marine Electronics Association (NMEA) 0183 Version 2.30, has a C4 criticality. The message, composed of 10 sub-messages, is transmitted at a rate of 1 Hz, with the exception of Heading True (HDT) at 8 Hz. The accuracy of the data is 100 m for position and 1 sec for time.

TABLE 2. Block 3 data output summary (continued).

System	Message Rate (Hertz)	Position Accuracy (meters)	Attitude Latency (msec)	Time Accuracy (msec)
Exp Port	Note 2	25	100	100
FODMS (Stanag)	40	N/A	N/A	N/A
FODMS (RS 422)	1	100	N/A	N/A
ICAN	50 Note 1	20	10	10
IP-1747 WSN-7	0.125 Note 1	N/A	N/A	N/A
MK-34 MK-160	8 Note 1	20	N/A	10
MK-86	1	20	N/A	100
METOC	1	16	100	N/A
Ndwmis	1 Note 1	16	100	N/A
NDDN	1	100	N/A	N/A
NMEA	1	100	100	100
Outboard	Synchro	100	N/A	N/A
SDMS	8	1000	60	1000
SSDS	50 Note 1	20	10	10
SWAN	50 Note 1	20	10	10
TCS	8	20	10	10
TDBM	1	100	N/A	1000
TRD-F	1	100	N/A	N/A
WSC-3	1	N/A	N/A	N/A

Note 1 Multiple messages, highest rate given.
Note 2 Rate is manually selectable as 1, 8, 16, or 50 Hz.

DISPLAY AND CONTROL SUBSYSTEM (DCS)

The NAVSSI DCS Sensor Data Segment (SDS) and U.S. Coast Guard Integrated Navigation Segment (COMDAC-INS) CSCIs provide the integrated human–computer interface (HCI) for the NAVSSI program. The HCI is available from both the DCS workstation console and the NRS.

The DCS provides NAVSSI operator, ship's navigator, and navigation watch team with tools to plan, monitor, and carry out ownship's navigation; the capability to access and display digital nautical charts (DNCs); the capability to control and monitor RTS operations; a display of navigation sensor data; the capability to record and retrieve navigation information; and the capability to serve as the display and control unit for the GVRC installed in each RTS.

COMDAC-INS is integrated with the DCS SDS to provide a full set of automated navigation tools to the operator. The Joint Mapping Toolkit (JMTK) utilities provided with the DII COE provide the required chart manipulation functions. In combination, NAVSSI's CSCIs provide a navigation system in compliance with U.S. Navy policies and procedures for vessel navigation.

DCS Input from the RTS(s)

The DCS can input data from the RTS(s) via the NAVSSI LAN. The NAVSSI LAN is either the existing shipboard Fiber Data Distributed Interface (FDDI) LAN or a dedicated NAVSSI FDDI LAN. Input data includes external interface communication status, navigation sensor data, alarm, alert, and warning messages from the RTS(s). Input errors and out-of-tolerance conditions are displayed at the DCS and NRS.

Input from the Workstations

The DCS accepts manually input data from the DCS workstation and the NRS. The DCS provides displays to facilitate the manual input of system configuration data including the hardware suite designation and the sensor and user interfaces installed on that particular ship. This includes system configuration data, OSRP and lever arm data, and input of position fixes, course, and speed.

Digital Nautical Chart Access

The DCS HCI is capable of accessing and displaying any of the DNCs produced by the National Imagery Mapping Agency (NIMA) in a convenient and timely manner in accordance with U.S. Navy navigation policy.

Navigation Sensor Data Displays

The DCS provides the NAVSSI operator with the ability to view the most recent navigation data for each of the available sensors such as INSs, GPS receivers, speed logs, depth sensors, wind sensors, manually entered position, course, and speed.

Depending on the particular type of navigation sensor, the data to be displayed includes some subset of the following: time, latitude, longitude, velocity north, velocity east, total velocity (speed over ground), course over ground (COG), ship's heading, attitude data, estimated position (EP), fathometer depth data, magnetic bearing data, true and relative wind speed and direction, source selection algorithm status, interface status, true bearings, radar ranges, and lines of position.

NAVSSI Navigation Status Displays

The DCS provides continuously displayed navigation status lines. The navigation status lines are updated whenever the displayed values change up to a maximum rate of once per second. The data displayed on the status display lines include lines for the following: universal time coordinated (UTC), latitude, longitude, COG, speed over ground (SOG), soundings, data recording status, system alert status, system alarm status, navigation source selection mode (automatic or manual), and INS fix source selection mode.

User Interface Status Display

The DCS generates a display for simultaneous monitoring of the status of each sensor and user interface. The display lists each sensor and user interface and indicates whether that interface is active, i.e., ENABLED or DISABLED. For sensor interfaces, the display also shows whether or not that sensor is a current source for navigation data and whether its selection as a data source is automatic or manual. For user interfaces, the display shows the data source it is receiving and whether that data source was selected automatically or manually.

Navigation History Displays

The DCS can display navigation history data logs for the preceding 24 hours at UTC rollover each day. The data logs are as follows: position and depth provided by NAVSSI, position and depth provided by external users, ship's distance, source selections, GPS fix data from antenna No. 1 and from antenna No. 2 (if installed), fix data applied to INSs (if installed), manually entered fix data, courses and speeds, NAVSSI system crash data, alerts and alarms, and accumulated ownship distance.

DCS Controls

The DCS operator can control all the functions carried out by NAVSSI using graphical user interface (GUI)-based HCI control functions.

Navigation Source Selection Control

The DCS enables the NAVSSI operator to select an operating mode for the navigation source selection algorithms of "Automatic" or "Manual."

INS Fix Source Selection Control

The DCS enables the NAVSSI operator to choose what sensor NAVSSI will use to provide data to the ship's INSs (AN/WSN-5s or AN/WSN-7s).

RTS Expansion Port Controls

In addition to the standard control functions that the DCS performs for all RTS interfaces, the DCS provides the capability to rename expansion ports. Once renamed, the DCS uses the new name in all windows that include the expansion ports.

Time Source Selection Controls

The DCS enables the NAVSSI operator to select a source of time for the RTSs and it provides an actual time for the RTSs to correct to. There are two modes of time source selection: "Automatic" or "Manual." The default mode is the Automatic Mode.

The RTS does not select the time source if that time source does not meet the criteria checklist. The RTS continues to use whatever time source it had been using, whether it had been chosen manually or automatically. The RTS provides an alert to the DCS to advise the user that the chosen source was unacceptable. Faults and failures with the precise time distribution shall be reported to the DCS as alerts.

Navigation History Data Logging

The DCS records the following time tagged navigation history data collected during the preceding 24 hours to non-volatile storage: position and depth as indicated at the DCS (0.1-Hz rate); position and depth provided to external users (1-Hz rate); ship distance; source selection history; GPS fix data from antenna No. 1 and from antenna No. 2 (if installed) (1-Hz rate); fix data applied as input to the INSs; manually entered fix data; courses and speeds; and NAVSSI alerts and alarms.

All data except the 0.1-Hz DCS position and depth file are maintained for a minimum of 24 hours before being overwritten. The 0.1-Hz DCS position and depth data are maintained for at least 45 days before being overwritten.

Data to Tactical Database Manager

The DCS provides navigation data to the shipboard Tactical Database Manager (TDBM) at a user-selectable rate. The TDBM Application Programming Interface (API) calls are used by the DCS to provide these data to the track database via the FDDI LAN.

Supply Almanac Data to TAMPS

The DCS can provide GPS almanac data to the Tactical Air Mission Planning System (TAMPS). The DCS can transmit the almanac files to TAMPS via the LAN. In addition, the DCS can save the data to a 3.5-inch floppy diskette for direct use by TAMPS.

Digital Mapping, Charting, and Geodesy (MCG) Product Serving

NAVSSI can serve NIMA digital MCG products to DII COE shipboard user systems via local network connections. NAVSSI can also provide these digital products to non-DII COE clients by providing raw data via Network File System (NFS) and will provide User Datagram Protocol (UDP) broadcasts to notify users of updates that have been made by the operator.

GVRC Controls and Displays

The DCS serves as the control and display unit for the GVRCs.

COMDAC–INS

The U.S. Navy and Coast Guard implemented a joint development effort for chart display and manipulation called Command Display and Control–Integrated Navigation Segment (COMDAC-INS). COMDAC–INS is a DII segment that serves as the charting segment in the NAVSSI Block 3 DCS as defined in the NAVSSI-B3-IRS-101. The DCS HCI is developed under the DII COE architecture to work with the COMDAC–INS in providing the capabilities described in the following sections.

ECDIS-N and DoD Interoperability Requirements

The COMDAC–INS is designed in accordance with the guidelines and performance standards outlined in the ECDIS-N Policy Letter [2]. It accepts inputs from Navy standard automated and continuous positioning systems. The COMDAC–INS will accept radar and visual navigation fix information.

Display Requirements

The COMDAC–INS is designed to display all system digital nautical chart (SDNC) information, which is subdivided into three categories: standard display, display base, and all other information. When a chart is first displayed, it provides the standard display at the largest scale available.

The system will display DNC information and updates without degradation of their information content once the chart update format is determined by NIMA. A "north-up" orientation is required, with others permitted. The system uses recommended International Hydrographic Organization

(IHO) colors provided by NIMA symbology set (GEOSYM) and is visible in both day and night conditions. The system can display SDNC information for route planning, monitoring, and supplementary navigation tasks.

Display of Other Navigational Information

Radar and other navigational information may be added to the COMDAC–INS display. The system is designed not to degrade the SDNC information and to remain clearly distinguishable from the SDNC information.

Route Planning

The system can carry out route planning in a simple and reliable manner. It provides for route planning (including straight and curved segments) and route adjustment (e.g., adding, deleting, or changing the position of waypoints to a route). It is possible to plan an alternative route in addition to the selected route. The selected route is clearly distinguishable from the other routes. The mariner can specify a limit of deviation from the planned route. An automatic off-track alarm when deviating from a planned route by the limit specified is provided. An indication is provided if the mariner plans a route across an own ship's safety contour or the boundary of a prohibited area or of a geographical area for which special conditions exist.

Route Monitoring

The system can carry out route monitoring in a simple and reliable manner. For route monitoring, the selected route and ownship's position normally appear whenever the display covers that area. It is also possible to display a sea area that does not have the ship on the display (e.g., for look ahead, route planning). If this is done on the display in use for route monitoring, the automatic route monitoring functions are continuous (e.g., updating ship's position, providing alarms and indications). It is possible to return immediately to the route monitoring display covering ownship's position by single operator action.

The system provides an alarm within a specified time set by the mariner if the ship is going to cross the safety contour. It provides an alarm or indication if the ship is going to cross the boundary of a prohibited area or of a geographical area for which special conditions exist. An alarm is given when the specified limit for deviation from the planned route is exceeded. The system provides an indication when the input from the position-fixing system is lost, and it also repeats, but only as an indication, any alarm or indication passed to it from a position-fixing system. An alarm is given if the ship is going to reach a critical point on the planned route within a specified time or distance set by the mariner.

The system continuously plots the ship's position. It provides for the display of an alternative route in addition to the selected route. The selected route is clearly distinguishable from the other routes.

The system displays time-labels along the ship's track and other symbols required for navigation purposes such as the following: own-ship past track with time marks for both primary and secondary track; vector for course and speed made good; variable range marker and/or electronic bearing line; cursor; event posting for both DR position and time and EP and time; fix and time; position line time; transferred position line and time for both the predicted and actual tidal stream or current vector with effective time and strength (in box); danger highlight; clearing line; planned course and speed to make good; waypoint; distance to run; planned position with date and time; visual limits of lights arc to show rising/dipping; and position and time of "wheelover."

Voyage Recording

The system can reproduce certain minimum elements required to reconstruct the navigation history and verify the official database used during the previous 12 hours. The system records the complete track for the entire voyage at intervals not exceeding 4 hours. These data are protected and it is not possible to manipulate or change the recorded information.

STELLA

Another program integrated into the NAVSSI DCS is the System to Estimate Latitude and Longitude Astronomically (STELLA). STELLA is a software module developed to provide an integrated set of planning and reduction tools for celestial navigation. STELLA consists of the NAVSSI GUI and a U.S. Naval Observatory (USNO)-developed computational engine (CE). The GUI accepts input data and user commands, calls the CE function to process data, and displays the returned data in text, table, or graphics forms. The CE performs all necessary astronomical and navigational functions.

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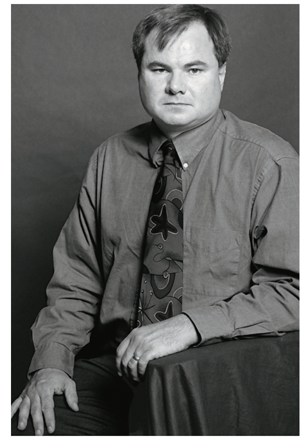

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HMS *Scott*: United Kingdom Ocean Survey Ship

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ABSTRACT
Minimizing the cost per survey mile while ensuring that survey products meet required standards is a prime consideration when evaluating oceanographic surveying systems. This was one of the prime factors that led to the United Kingdom Ministry of Defense Procurement Executive (UK MOD PE) selection of a U.S. Navy designed ocean survey system to be installed aboard a new construction ship. The 13,500-ton HMS Scott *was designed and built specifically to accommodate the U.S. survey system and is considered the UK's premier survey ship. The mission of HMS* Scott *is to gather, process, and record time-correlated bathymetric, gravity, magnetic, and other oceanographic data as a function of latitude and longitude. Since deployment in early 1998, HMS* Scott *has successfully conducted highly accurate bathymetric surveys at an average sustained speed of 12 knots in ocean depths ranging from 50 fathoms to approximately 2500 fathoms in various types of terrain, from flat to very high relief.*

BACKGROUND

In 1963, the U.S. and the Government of the United Kingdom of Great Britain and Northern Ireland (UK) signed the Polaris Sales Agreement. The U.S. agreed to sell to the UK Polaris missiles (less warheads), equipment, and supporting services related to support of the UK Polaris submarine fleet.

As part of this support effort, the U.S. also shared, with the UK, ocean-bottom maps generated by a U.S. Navy developed wide-swath, multi-beam bathymetric navigation system. This system, the first of its kind, was installed aboard three deep-ocean U.S. Navy survey ships and, for a period of more than 35 years, produced the highly accurate bathymetric charts required by the U.S. and UK Fleet Ballistic Missile (FBM) submarines.

In 1987, the UK Ministry of Defense (MOD) decided to update its ocean-surveying capability. After evaluating several candidate systems, the MOD concluded that the only system capable of meeting its FBM submarine requirements was the system developed and used by the U.S. Navy. Therefore, in 1995, the UK MOD approved construction of the 13,500-ton HMS *Scott*, shown in Figure 1, and specified that the ship was to be designed and built specifically to accommodate the U.S. Navy developed, fully integrated Ocean Survey System (OSS).

FIGURE 1. HMS *Scott*.

HMS *SCOTT* DESCRIPTION

HMS *Scott*, built by Appledore Shipbuilders Ltd. of North Devon, England, was handed over to the Royal Navy in 1997. She was designed to operate in areas remote from normal shipping lanes, in changeable severe weather conditions, and on a schedule of nine 35-day cycles each year, surveying for 24 hours a day when tasked [1]. Table 1 shows HMS *Scott* principal characteristics.

Figure 2 is a profile drawing of HMS *Scott* showing locations of mission-related spaces. Within these spaces are housed the elements that make up the OSS that will be discussed in this paper.

TABLE 1. HMS *Scott* principal characteristics.

Length	130 meters
Beam	21.5 meters
Design survey draft	8.3 meters
Displacement	13,300 tons
Survey speed	15 knots
Machinery plant	Diesel/Single screw
Endurance	35 days at survey speed
Thrusters	Bow
Crew	65

MISSION SYSTEM DESCRIPTION

The mission of HMS *Scott* is to gather, process, and record time-correlated bathymetric, gravity, and other ocean-related data. This paper will address only the mission of gathering bathymetric data, as accomplished by the OSS.

The entire OSS is supported by a dedicated, regulated power system, also developed by the U.S. Navy. Figure 3 is a simplified block diagram of the OSS.

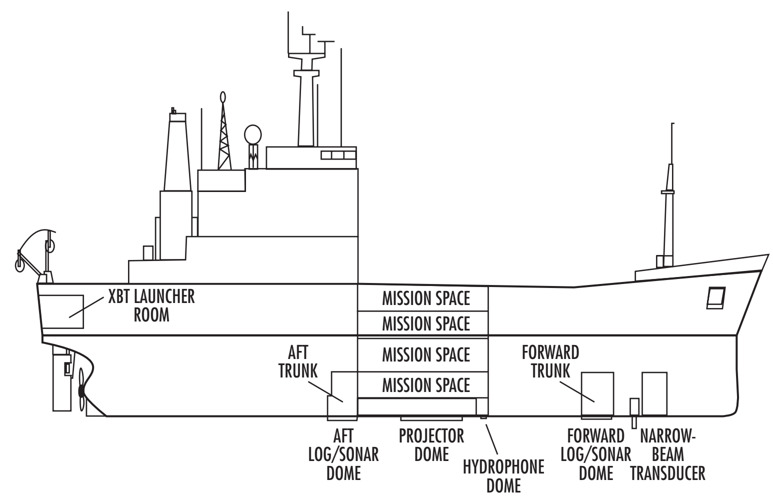

FIGURE 2. HMS *Scott* profile.

NAVIGATION SUBSYSTEM

The Navigation Subsystem provides precise and accurate platform attitude, position, and velocity information as a function of time for correlation with depth and other recorded survey data to produce specialized charts. Figure 4 is a simplified functional block diagram of the Navigation Subsystem.

The heart of the Navigation Subsystem is the navigation computer that performs the data integration, monitoring, and control functions that coordinate overall operation of the Navigation Subsystem.

Position data from Loran-C receivers, the Global Positioning System (GPS), and the Miniature Ship's Inertial Navigation System (MINISINS) are prioritized and filtered by the navigation computer program to produce the best present position (BPP) output. BPP is supplied in terms of latitude and longitude to the Sound Velocity System (SVS), Gravity System, and the Mission Control and Processing Subsystem (MCAPS). The MCAPS consists of the Survey Control System (SCS), System Analysis Station (SAS), and the Data Refinement System (DRS).

Velocity data, including vertical velocity, are received by the navigation computer program, and those inputs from the selected velocity source are distributed to the wide-swath-array sonar and to the Gravity System.

Attitude data are provided from both the MINISINS and the MK-29 Gyrocompass, a backup to the MINISINS. Source selection and distribution of the data are accomplished by the Ship's Attitude Data Converter (SADC). Heave data, developed in the heave processor, are distributed along with attitude data.

Roll, pitch, heading, and heave data are supplied to the Sonar Subsystem. Roll, pitch, and heading are also provided to the navigation computer to compensate for antenna lever arms to the ship's reference point. Heading is supplied to the shipboard heading indicators, ship's auto-pilot, and the SCS.

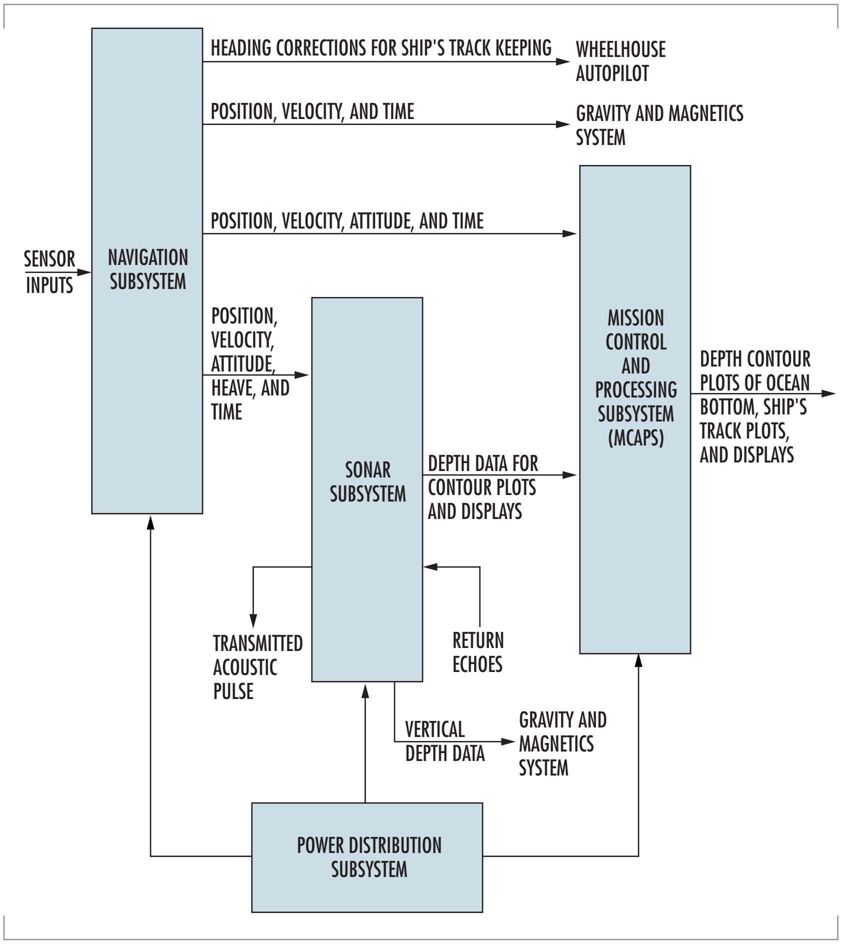

FIGURE 3. Simplified Ocean Survey System block diagram.

Heading corrections are developed by the navigation computer program and supplied to the ship's auto-pilot for use during track-keeping operations. The heading corrections are combined with the auto-pilot steering commands and cause the ship to steer over a prescribed ground track instead of steering to a prescribed heading. This capability provides high-quality, tight track control.

SONAR SUBSYSTEM

The Sonar Subsystem consists of a wide-swath-array sonar and a single-beam sonar. Figure 5 is a simplified block diagram of the entire Sonar Subsystem. The wide-swath-array sonar obtains rapid acquisition of high-resolution sonar data as a function of time as the ship progresses along a desired track. The system employs a 120-degree, fan-shaped acoustic swath pattern that is transverse to the ship's track (see Figure 6) and operates in depths ranging from 50 fathoms to beyond 6000 fathoms.

To obtain depth measurements, the system transmits a 7-ms pulse every 12 or 15 seconds in deep water, and a 3-ms pulse every 3 or 6 seconds in shallow water. The transition from 12 to 15 seconds takes place at approximately 2000 to 2400 fathoms to allow for increased processing time. The transmit frequency is 12 kHz with each ping consisting of a 7-ms pulse. The returning echoes, received by the 144 hull-mounted hydrophones, are sampled every 3-ms to give time snapshots of the

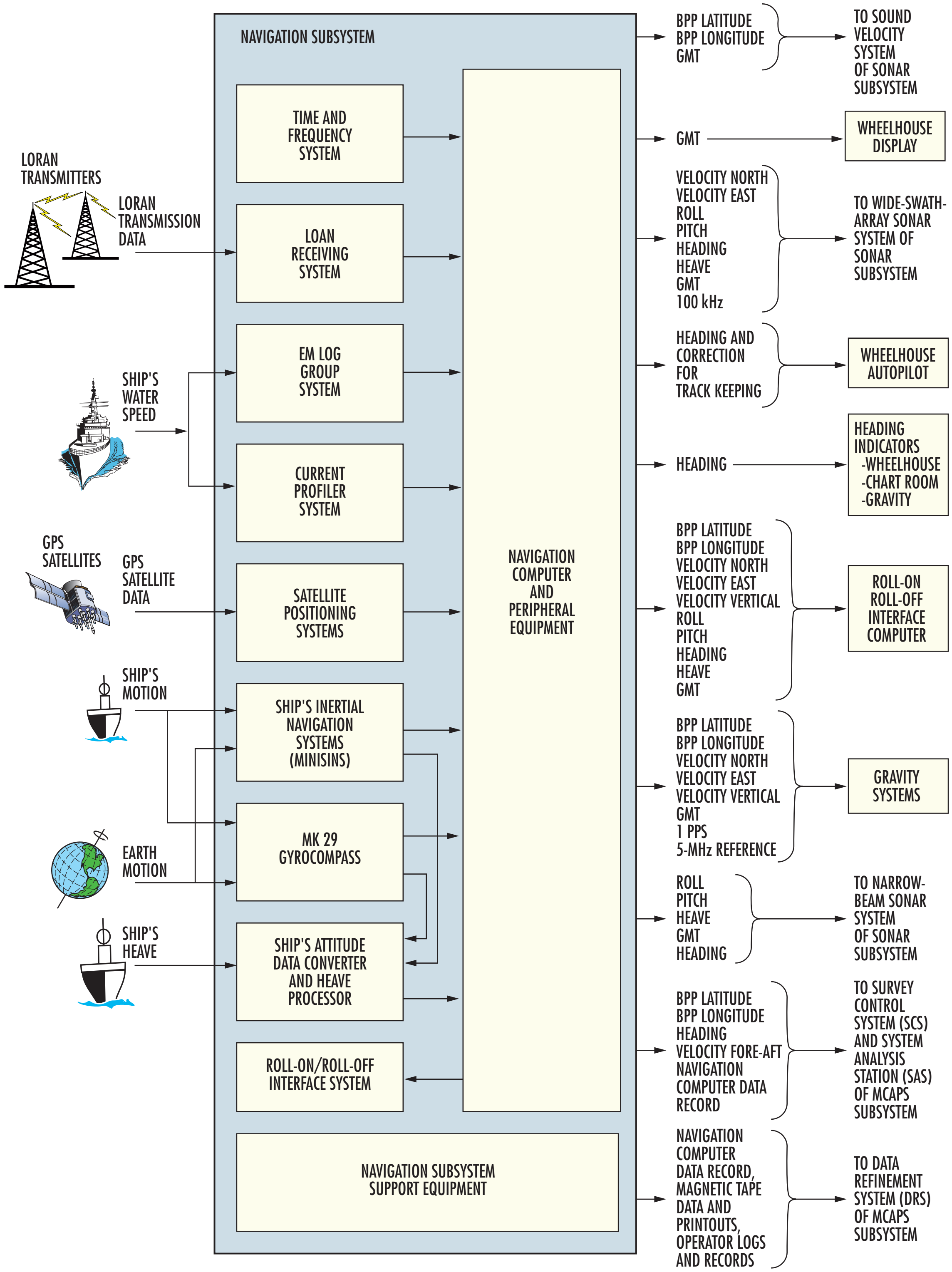

FIGURE 4. Navigation Subsystem.

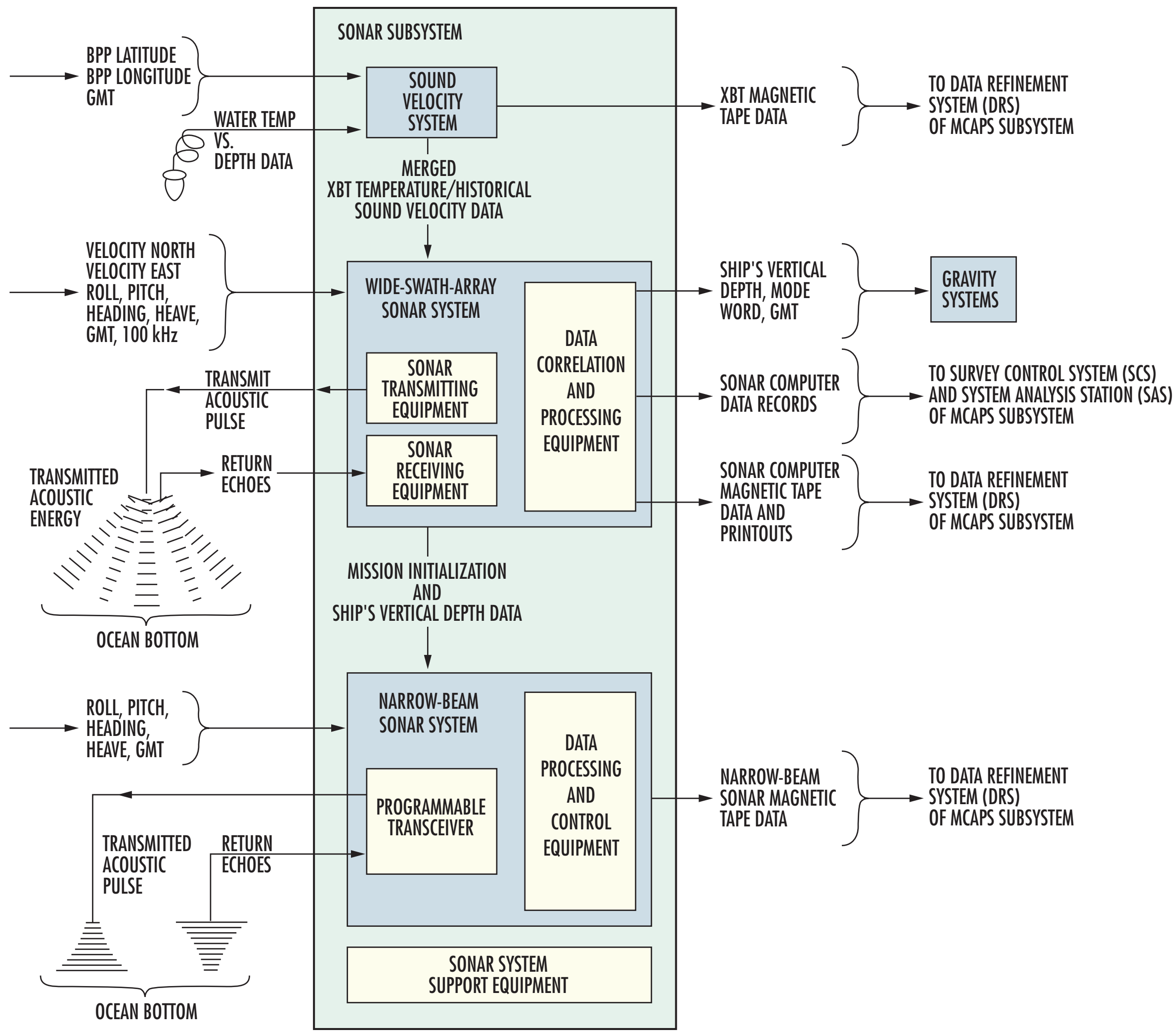

FIGURE 5. Sonar Subsystem.

acoustic pulse reflected from the bottom. Digital signal-processing algorithms process up to 1664 time snapshots of the returning signal to develop an across-track profile of the bottom, with an average internal resolution of a third of a degree across the swath. The profile is then decimated to 121 bottom points spaced 1 degree apart. Each point is then corrected for sound-velocity variations and for roll, pitch, heading, and heave variations between time of transmission and reception. The data are then checked for validity and reasonableness by the on-line software.

Transmission takes place with the projection of a burst of acoustic energy (from 58 projectors mounted in the fore-aft direction along the ship's centerline) that ensonifies a narrow strip of the ocean floor. The width of the ensonified strip extends beyond the 120-degree swath pattern. Compensation for pitch angles of up to ±10 degrees is applied during transmission to steer the projected acoustic energy beam to the vertical about the pitch axis. Acoustic echoes returning within the 120-degree swath pattern are captured by an array of 144 hydrophones (mounted athwartship and forward of the projector array) for processing. The swath pattern is roll-corrected to the vertical. Compensation for roll angles of up to ±15 degrees is applied to returns upon reception to keep the swath pattern fixed relative to the vertical about the roll axis.

Figure 7 shows wide-swath-array sonar depth versus bottom coverage. For depths down to 1000 fathoms, each transmission, or ping, provides 121 depth points over a data-acquisition swath that is 3.5 miles wide. As depths go beyond 1000 fathoms, the number of measurable data points captured within the 120-degree swath pattern gradually begins to diminish. At a depth of 5000 fathoms, each ping provides 91 depth points over a data-acquisition swath that is 12 miles wide. To allow for the varied acoustic-signal travel times associated with shallow and deep depths, the system employs operator selected ping rates of 3, 6, 12, or 15 seconds.

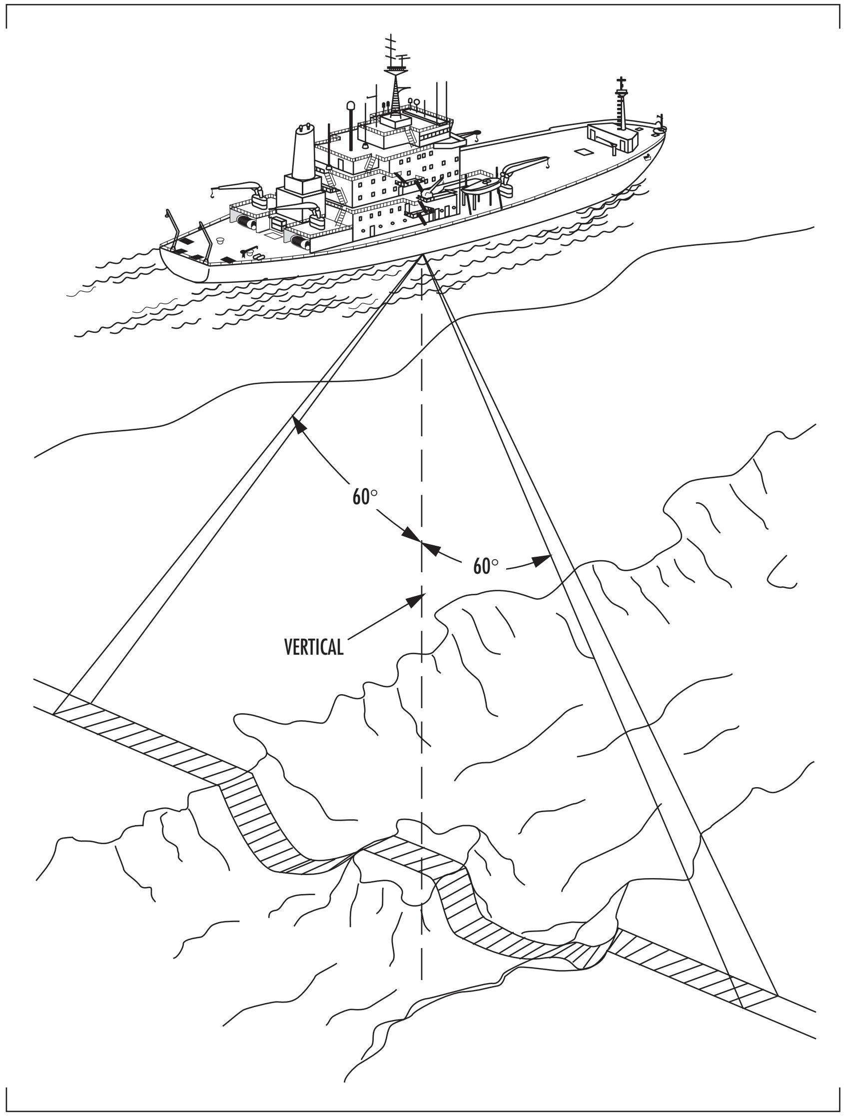

FIGURE 6. Wide-swath-array sonar beam pattern.

Sound-velocity corrections are applied by using periodic expendable bathythermograph (XBT) casts to measure the ocean water temperature as a function of depth. These water temperature versus depth measurements provide the means to detect a significant change in the sound-velocity structure of the local ocean area of interest and to determine the applicability of the sound-velocity-versus-depth profile in current use by the Sonar Subsystem. The XBT cast data are merged with historical sound-velocity data and sent to the Sonar Subsystem for use during returned echo data processing.

The single-beam sonar uses a 9-degree conical pattern (see Figure 8) and obtains and records the ocean depth directly beneath the ship. This sonar provides an independent method of monitoring the vertical-depth data output of the wide-swath-array sonar. When the wide-swath sonar is off-line, such as when the ship is in water less than 50 fathoms or when it is inoperative, the single-beam sonar performs the depth-acquisition function of the OSS.

MISSION CONTROL AND PROCESSING SUBSYSTEM

The MCAP Subsystem (Figure 9) provides centralized control and performance monitoring of overall OSS operation. The MCAP Subsystem consists of three systems: Survey Control System (SCS), Systems Analysis Station (SAS), and Data Refinement System (DRS), all interconnected over a Local Area Network (LAN).

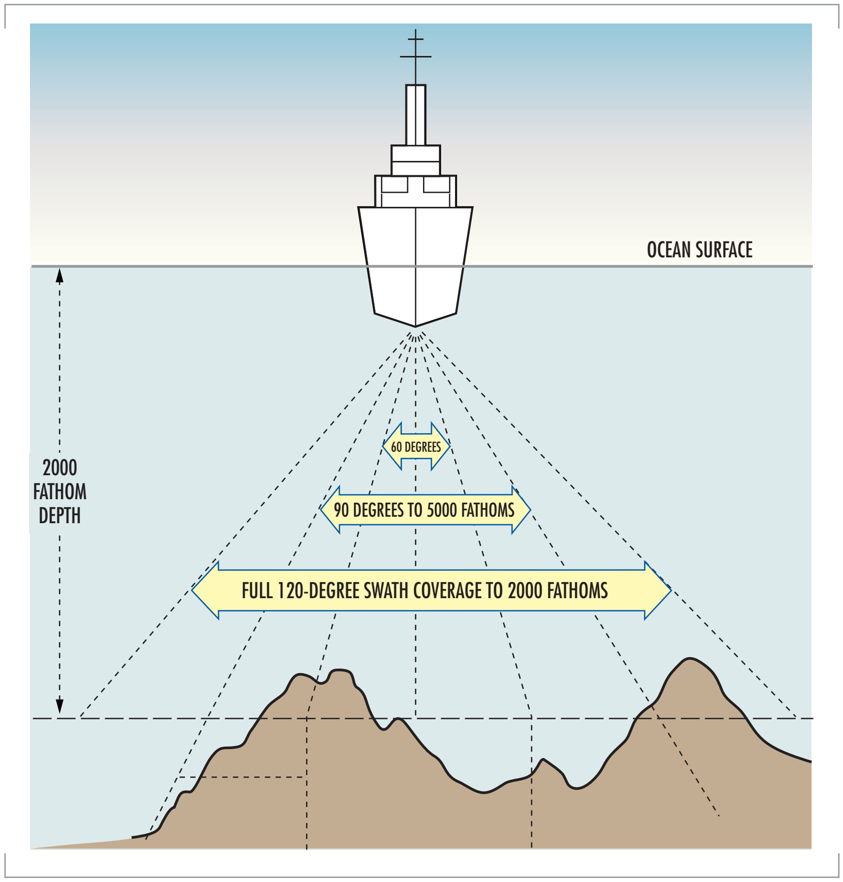

FIGURE 7. Wide-swath-array sonar coverage vs. depth.

SURVEY CONTROL SYSTEM

The SCS provides remote-operator control functions for the navigation and sonar computers along with graphical data displays necessary to support on-line survey operations. The SCS provides a centralized, on-line, survey-system control workstation that provides the following four major functions: (1) initialization of the navigation and wide-swath-array sonar computer programs, (2) performance of system mode changes, resets, and parameter updates, (3) survey data collection, and (4) displays of graphical and tabular data providing high-level representations of the current navigation and sonar data being collected, as well as a display of ship's progress along the prescribed survey track.

SCS display functions include the high-level graphical and tabular data displays necessary for the operator to quickly assess and ensure that data collected by the Navigation and Sonar Subsystems meet survey mission requirements.

SYSTEM ANALYSIS STATION

The SAS serves as the central workstation for control of plotting functions, and on-line system performance analysis, monitoring, and troubleshooting through a comprehensive set of graphic displays. Some of the graphic displays that the operator can select to examine system performance, both in near-real-time or post-time are plots of position, velocity, ship's track, or depth contours. A database of up to 50 days' worth of data can be accessed by the operator for review and analysis.

DATA REFINEMENT SYSTEM

The DRS provides post-time data refinement functions for data collected by the OSS. This off-line, computer-based processing system post-time processes shipboard-gathered sonar and navigation data and produces the final, fleet-ready bathymetric chart product. Specifically, the DRS develops refined position and velocity navigational data; generates hard-copy and screen displays of bathymetric navigation charts; and edits, analyzes, displays, and compresses the wide-swath sonar data.

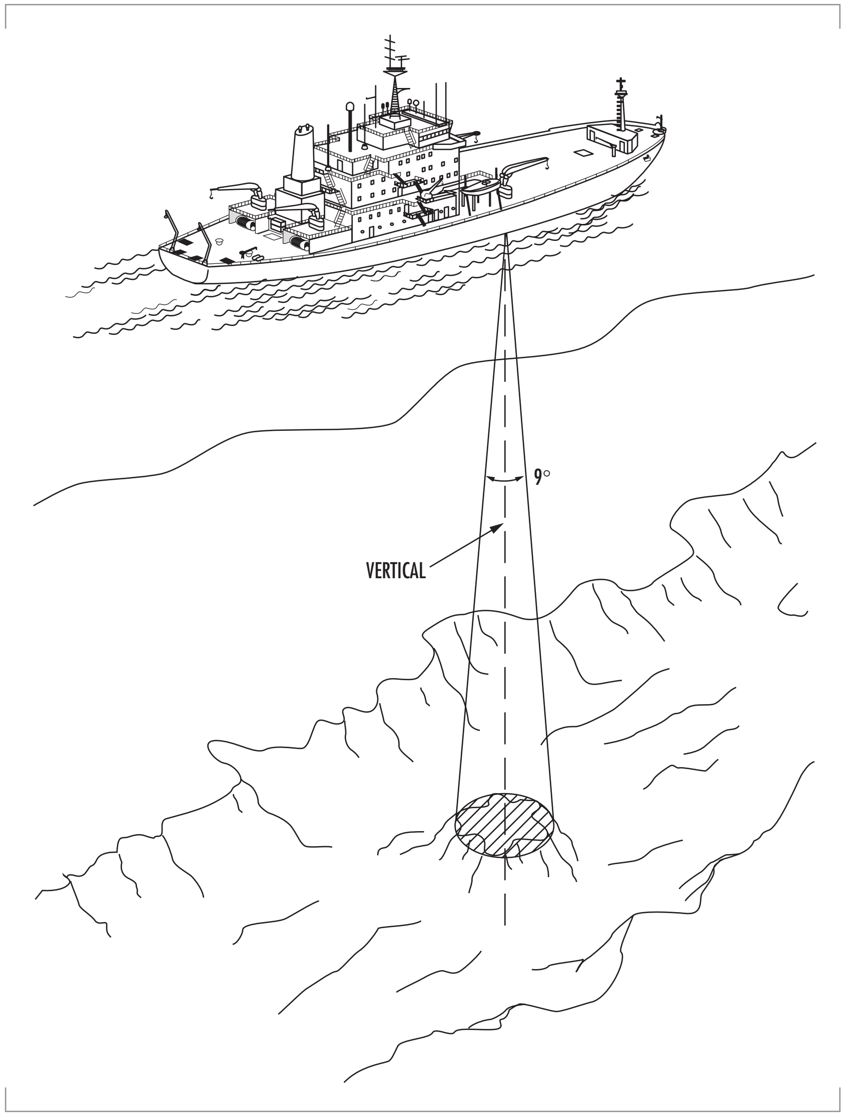

FIGURE 8. Single-beam sonar system beam pattern.

POWER DISTRIBUTION SYSTEM

The primary function of the Power Distribution System (Figure 10) is to provide precision-regulated and signal-conditioned 60- and 400-Hz power to all OSS equipment. A secondary, but equally important function is to maintain a continuous emergency back-up power supply for critical equipment if the main power supply should fail. The 60- and 400-Hz power distribution systems receive power from the ship's service diesel generators via the ship's main service power panel.

The 60-Hz power distribution system provides 120-V, 60-Hz, three-phase power to the 60-Hz regulated power panels of the OSS. The 60-Hz power distribution system consists of two regulated power systems and one uninterruptible power source (UPS). The 400-Hz power distribution system provides 120-V, 400-Hz, three-phase delta output power to the OSS. The 400-Hz power distribution system consists of two separate and independent systems. Each system uses one 400-Hz UPS equipment cabinet and one 400-Hz UPS battery cabinet. Only one 400-Hz system is on at a time. The second system is maintained in an active standby operating mode.

The alarm and monitoring equipment associated with the Power Distribution System consists of the following items: (1) a power disturbance analyzer that monitors, measures, records, analyzes, and prints the type of disturbances that occur in the 60- and 400-Hz power distribution systems; (2) 60- and 400-Hz alarm and monitor panels that monitor AC voltages, AC current, and frequencies of the vital equipment power panels; (3) 60- and 400-Hz UPS remote status panels that monitor and provide a visual operating status of the UPS systems including battery condition and that provide visual and audible alarms for system changes.

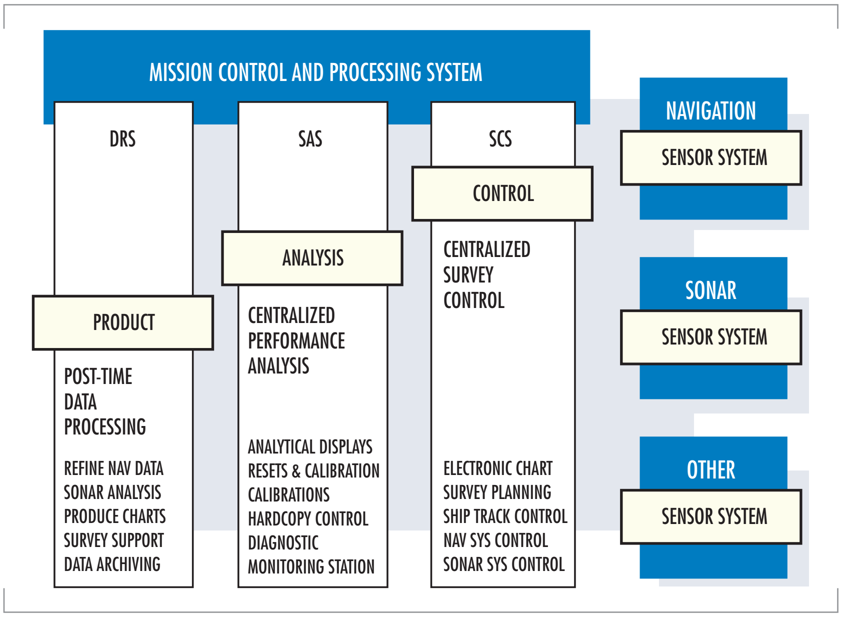

FIGURE 9. Mission control and processing system.

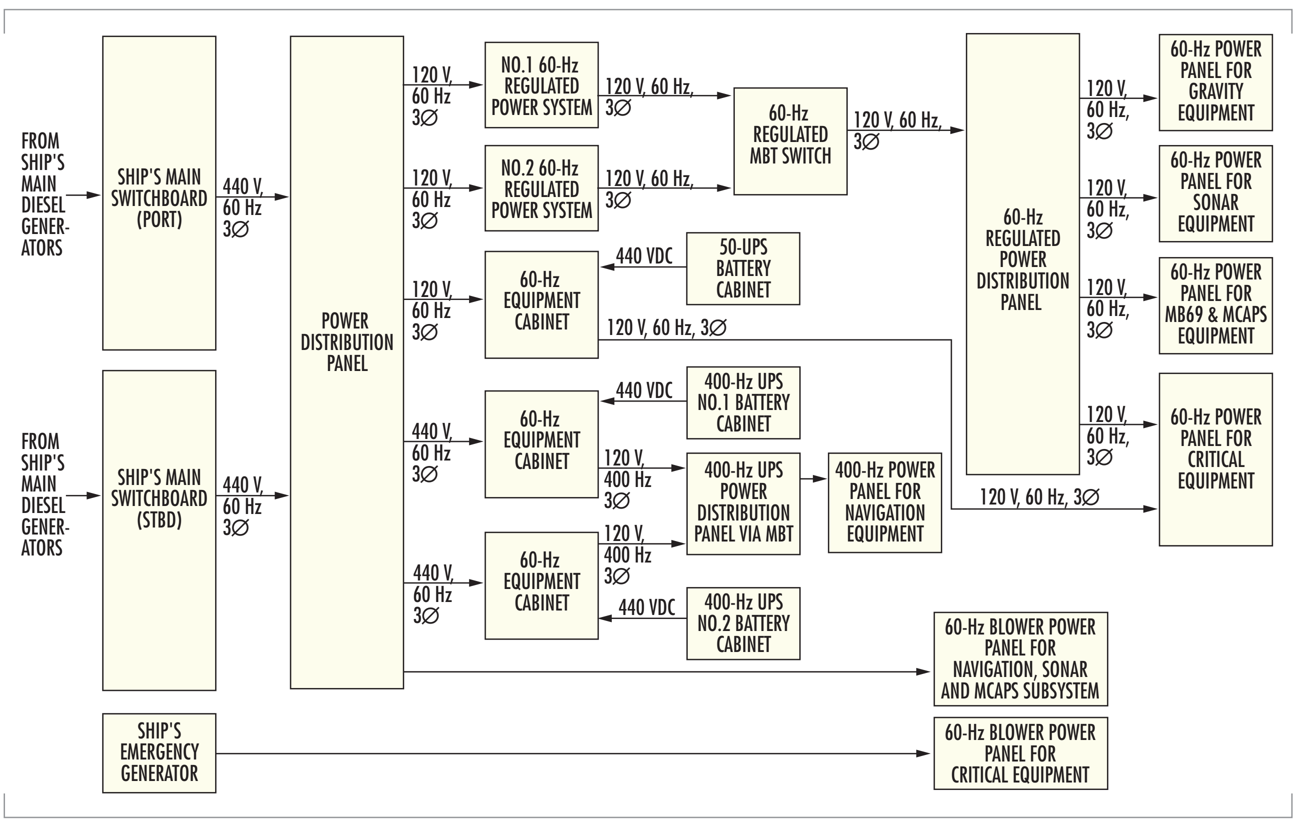

FIGURE 10. Power Distribution System.

CONCLUSION

The HMS *Scott* OSS described in this paper has been in operation since January 1998 and has provided the UK with a large volume of exceptionally accurate and detailed ocean-bottom data. At an average speed of 12 knots, approximately 10,000 survey miles can be achieved during a 35-day survey operation. Since the proven reliability of the OSS is greater than 99 percent, and given a specified minimum ship life of 25 years, it is expected that HMS *Scott* will provide large volume, very cost-effective, highly reliable, and very accurate oceanographic and bathymetric data over its operational lifetime.

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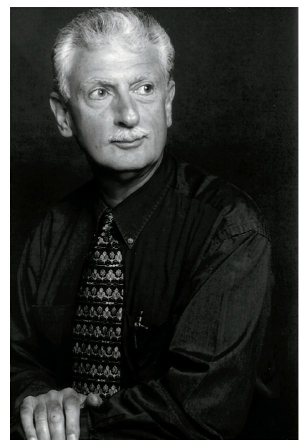

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The Use of Field Screening or Rapid Sediment Characterization (RSC) Tools for Sediment Assessments

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ABSTRACT
This paper discusses several rapid site characterization (RSC) technologies that can be used at marine sediment sites, including X-ray fluorescence (XRF) for metals, ultraviolet fluorescence (UVF) for polycyclic aromatic hydrocarbons, QwikSed bioassay for assessing toxicity, and other techniques. Examples are provided to illustrate the efficacy of applying RSC tools to different stages of the Ecological Risk Assessment (ERA) process. Finally, recommendations are given for the evaluation, selection, and application of RSC tools for the ERA process.

INTRODUCTION

The primary goals of a sampling and analysis plan for an Ecological Risk Assessment (ERA) or a sediment site assessment are to identify potential contaminant sources and to delineate areas of concern. However, traditional sampling and analysis approaches do not always provide the information necessary to support the decision-making process in a cost- and time-effective manner. Site assessments performed in the marine environment are often hindered due to the complexity and heterogeneity of marine ecosystems. Because of the complex nature of marine ecosystems, U.S. Navy policy [1] specifically requires that sampling programs focus primarily on the identification of potential contaminant sources and on the delineation of areas of contaminated media. Navy policy further dictates that sampling programs should make use of advanced chemical and biological screening technologies, data quality objectives, and statistical procedures to minimize overall sampling requirements. Implementation of advanced chemical, physical, and/or biological screening technologies (i.e., rapid sediment characterization tools) at different stages of the ERA process can aid in focusing sampling requirements and can ultimately facilitate reaching final decisions.

WHAT IS RAPID SEDIMENT CHARACTERIZATION?

Rapid sediment characterization (RSC) tools are field-transportable analytical tools that provide measurements of chemical, physical, or biological parameters on a near real-time basis. A variety of tools exist that are capable of making these types of measurements. Many technologies have been used to characterize different types of environmental media (e.g., soil, sediment, water, and air). These technologies are described in several Environmental Protection Agency (EPA) documents [2 and 3], including the online Field Analytical Technologies Encyclopedia (FATE) [4]. This encyclopedia provides information about technologies that can be used in the field to characterize contaminated soil and ground water, to monitor the progress of remedial efforts, and in some cases, to confirm sampling and analysis for site closeout. Although not all of the technologies currently available are applicable to sediment sites, several have been tested and demonstrated at Navy marine sediment sites (Table 1). Examples can also be found in standard environmental textbooks such as Gilbert's 1987 *Statistical Methods for Environmental Pollution Monitoring*, which provides specific examples of the use of screening and laboratory data together to optimize for reduction in cost and data variability [5].

WHY IS RCS IMPORTANT?

An ERA evaluates the likelihood that exposure to one or more stressors (e.g., contaminants) will result in adverse ecological effects [6]. The purpose of the assessment is to provide information relevant to the management decision-making process. Ideally, ERAs should be scientifically based, defensible, cost-effective, and protective of human health and the environment (see, for example, [1]). Collection of data necessary to support decisions at sediment sites in a cost-effective manner is often hindered by the complexity and heterogeneity of marine ecosystems. Detailed site investigations require extensive sampling and subsequent laboratory analyses for both metal and organic contaminants. Samples are often collected without any *a priori* knowledge of the nature and extent of contamination. Because of the high cost of laboratory analyses, the number of samples taken is often cost-limited. Thus, zones of contamination can be missed or, if located, overestimated or underestimated. To obtain more detailed spatial information on the extent of contamination, researchers must often sample and analyze sites of interest in an iterative manner. Chemical assays are often combined with additional laboratory analyses, including one or several bioassays to determine whether there are adverse biological effects of these contaminants in various media (e.g., sediment, elutriate, water column). This approach can be prohibitively costly, slow, and labor-intensive. When used appropriately, RSC tools can streamline many aspects of the ERA process, delineating areas of concern, filling information gaps, and ensuring that expensive, certified analyses have the highest possible impact.

TABLE 1. Examples of rapid sediment characterization tools tested in marine sediments.

Analytical Technique	Parameter(s)
X-ray Fluorescence (XRF) Spectrometry	Metals (e.g., Cu, Zn, Pb)
UV Fluorescence (UVF) Spectroscopy	Polycyclic Aromatic Hydrocarbons (PAHs)
Immunoassays	Polychlorinated biphenyls (PCBs), PAHs and Pesticides
QwikSed Bioassay Microtox	Acute and Chronic Toxicity Acute Toxicity
Laser Particle Scattering	Grain Size (% fines)

To determine if RSC tools are appropriate to assess contamination at a given site, several questions should be asked. For example: What are the goals of the investigation? What are the contaminants of concern? Are the contaminants known? What are the action limits? What are the strengths and weaknesses of the analytical methods being considered? Do instrument detection limits meet action limit requirements? By asking these questions before sampling begins and by considering the advantages and disadvantages of different techniques, appropriate decisions can be made on how best to implement a technology or suite of technologies to facilitate the ERA process. Table 2 lists the relative advantages and limitations of RSC methods and standard methods. A brief description of some RSC technologies that have been tested in sediments is provided below. All of these technologies described are commercially available.

TABLE 2. Advantages and limitations of screening and standard laboratory methods.

RCS Analysis	Standard Laboratory Analysis
Benefits · rapid results can guide sampling locations · potential for high data density for mapping · reduced cost per sample	Benefits · standard methods that are very quantitative · can often remove interferences
Limitations · often non-specific · semi-quantitative · matrix sensitive	Limitations · often blind-sampling · long delays to results · expensive ($K/sample)

EXAMPLES OF RSC TECHNOLOGIES: GENERAL PRINCIPLES

X-ray Fluorescence Spectrometry Metals

Commercially available, portable X-ray fluorescence (XRF) spectrometry analytical instruments can provide rapid, multi-element analysis of metals in sediment. Samples are exposed to X-ray energy, which liberates electrons in the inner shell of metal atoms. As the outer electrons cascade toward the inner shells to fill the vacancies, energy is released, or fluoresced. The fluorescing energy spectrum identifies the metals and each peak's intensity is proportional to concentration. Generally, XRF can detect and quantify elements from sulfur to uranium. For common metals, such as lead, zinc and copper, this method yields a detection limit range from 50 to 150 parts per million (ppm) and requires 2 to 5 minutes per analysis in soils and sediments. Commercial XRF instruments are readily available for purchase (~ $11,000 to $56,000) or lease (~ $150/day to $6000/month) depending on options and equipment size required. To accommodate field application, many instruments weigh less than 30 pounds and can be operated with batteries for 8 to 10 hours [4 and 7].

Ultraviolet Fluorescence Spectroscopy: PAHs

Fluorescence is a standard analytical technique that can be used to measure the concentration of various analytes in different matrices. Ultraviolet fluorescence spectrometry (UVF) can be used for the determination of polycyclic aromatic hydrocarbons (PAHs) in sediments. This technique is based on the measurement of fluorescence observed following UV excitation of either bulk samples or organic solvent extracts of sediments. However, detection limits are greatly enhanced by extraction. When UV light is passed through a sample, the sample emits light (fluorescence) proportional to the concentration of the fluorescent molecules (e.g., PAHs) in the sample [8]. An analysis, with extraction, can be done in 10 to 30 minutes, and for PAHs, the range for detection limits when using UVF is from 1 to 5 ppm total solid phase. UVF instruments are commercially available from various vendors for purchase (~ $10,000 to $12,000) or for weekly rental.

Immunoassays: PCBs, PAHs, Pesticides

This technique can be used for the identification and quantification of many organic compounds (e.g., polychlorinated biphenyls [PCBs], PAHs, and pesticides). Immunoassays use antibodies that have been developed to bind with a target compound or class of compounds. Concentrations of analytes are identified through the use of a sensitive colorimetric reaction. The determination of the target analyte's presence is made by comparing the color developed by a sample of unknown concentration with the color developed by a standard containing the analyte at a known concentration. The concentration of the analyte is determined by the intensity of color in the sample and is measured through use of a spectrophotometer. Immunoassay kits are relatively quick and simple to use. Several test kits are commercially available and range in cost from $10 to $40 per sample test kit. Detection limits can vary, depending on the dilution series used. For example, the detection limit for PCBs in sediments ranges from 50 to 500 parts per billion (ppb) [4 and 9].

Screening Bioassay Tests

The Microtox bioassay is a commercial test that measures the inhibition of light emitted by a bioluminescent microorganism. Any decrease in light output relative to controls suggests bioavailable contaminants or other stressors. Several studies have compared Microtox response to other bioassays (e.g., [10]).

The QwikSed rapid bioassay system is proving to be a valuable asset for conducting bioassays on marine sediments. The basis of detection is to measure a reduction in light from a bioluminescent dinoflagellate such as *Gonyaulux polyedra* or *Ceratocorys horrida* following exposure to a toxicant. The toxic response is usually measured within 24 hours from the start of the test and can be conducted for a 4-day acute test or a 7- to 11-day chronic test. A measurable reduction or inhibition in bioluminescence indicates an adverse effect. The cost of the QwikSed analyzer (Sealite Instruments, Inc., Ft. Lauderdale, FL) and supporting software is approximately $15,000. The data from the QwikSed bioassay can be correlated with more conventional toxicity tests such as amphipods and sea-urchin development.

RAPID CHARACTERIZATION TOOLS IN THE ERA PROCESS

The Chief of Naval Operations (CNO) Policy for conducting ERAs identifies a three-tiered approach that incorporates different levels of assessment complexity.

· Tier 1 - Screening Risk Assessment (SRA) (Steps 1 and 2)
· Tier 2 - Baseline Ecological Risk Assessment (BERA) (Steps 3 to 7); and
· Tier 3 - Evaluation of Remedial Alternatives (Step 8)

This approach, which is consistent with the EPA Superfund Interim Final Ecological Risk Assessment Guidance for Superfund [6] consists of eight steps (Figure 1). RSC tools can be used to assist several step of this process.

Screening Risk Assessment

The goal of a Screening Risk Assessment (SRA) is to determine whether an exposure pathway is present between each chemical of interest and selected ecological receptors and to estimate risks for those chemicals for which pathways are identified. Such an assessment should employ existing data, and should not require additional data collection. Site data, however, do not always exist. If data are lacking, rapid characterization can map the extent of contamination in order to guide sampling for full contaminant of potential ecological concern (COPEC) analysis. By using

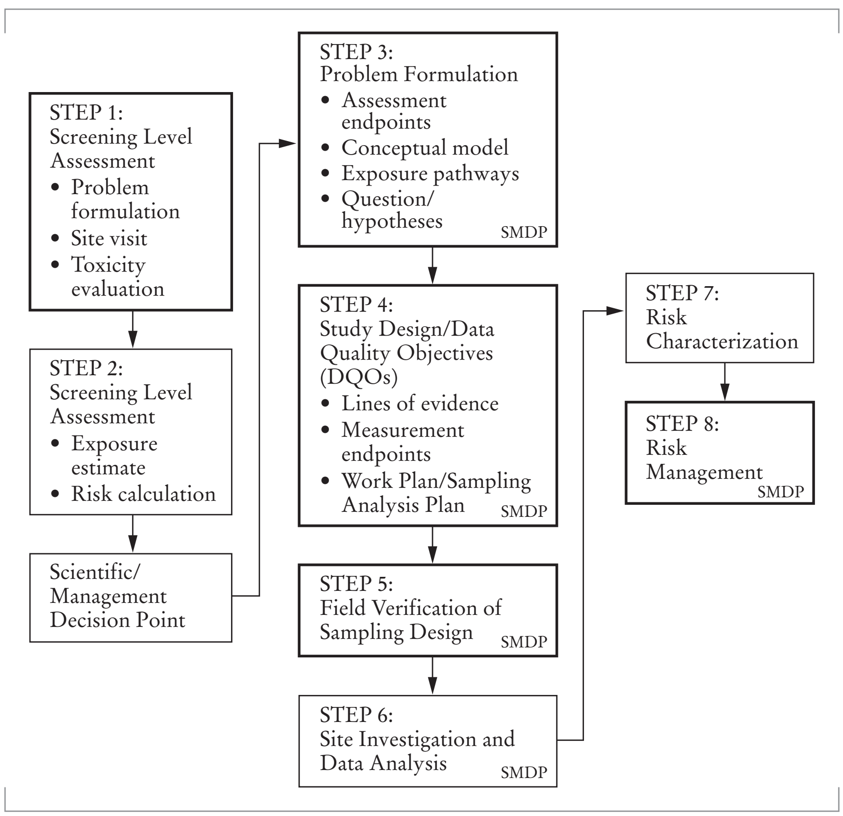

FIGURE 1. Navy Ecological Risk Assessment approach. Highlighted boxes indicate steps in which RSC tools can be used to facilitate the process.

RSC data to quickly map the area under investigation, subsequent sampling for full COPEC analysis can be more focused.

Baseline Ecological Risk Assessment

A Baseline Ecological Risk Assessment (BERA) is typically the most extensive activity within the ERA process, in terms of data collection and analysis, cost, and effort. There are several steps within the BERA in which rapid characterization tools can play a critical role, including Problem Formulation, Study Design/Data Quality Objectives (DQO) Process, and Verification of Field Sampling Design.

For example, two RSC tools were used for a sediment screening study at Hunters Point Shipyard to support a BERA sampling design (Steps 4 and 5). Surface sediment samples were collected in a grid-pattern from 94 locations in the five offshore areas of concern. Samples were screened for PCBs and heavy metals using the immunoassay technique and XRF spectrometry, respectively, at the SSC San Diego laboratory. The results were used to refine the sampling design for a more detailed study of sediment chemistry, toxicity, and bioaccumulation. In particular, screening results were used to ensure that the baseline assessment study sampling stations spanned the entire range of contaminant concentrations and, therefore, represented the full range of potential exposure. Ten percent of the screening samples were submitted to a standard analytical laboratory in order to obtain a quantitative analysis of all contaminants of concern, verify screening results, and provide additional surface sediment data supporting the assessment study.

Plots of PCB and copper (Cu) results are shown from one of the five offshore areas of concern (Figure 2). These results indicate two potential source areas for elevated PCBs in these offshore sediments, one on the northeast side and one on the west side of the embayment. Although the northeast area may be impacted by Navy operations, the source area to the west is at a creek mouth with potential non-Navy contributions of the target analytes from upstream locations onto Navy property. In the case of Cu, one potential source is indicated on the northeast side of the embayment, again potentially related to Navy operations. The screening

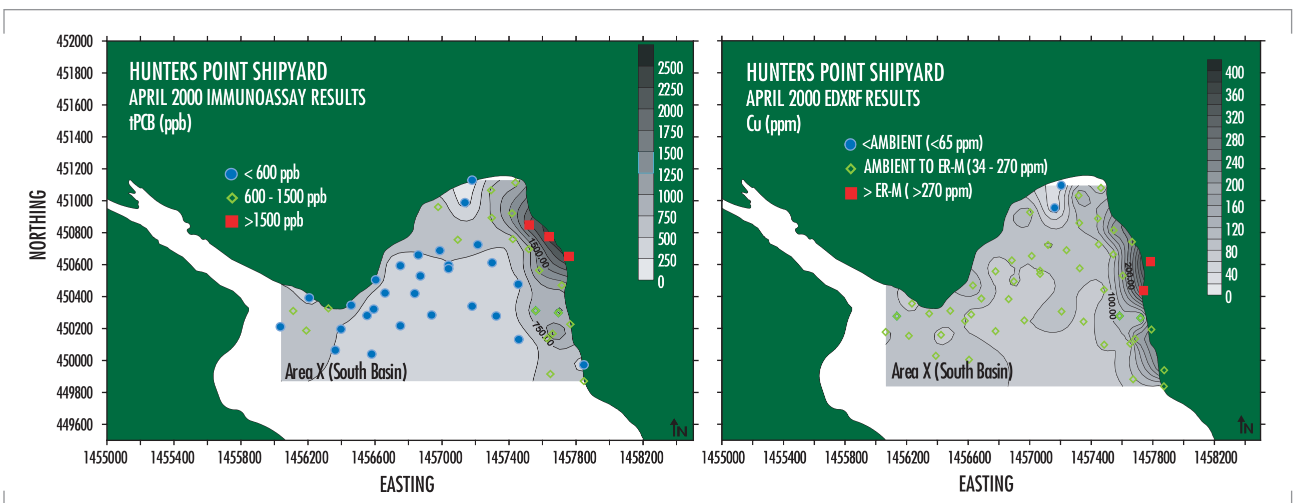

FIGURE 2. RSC tools implemented during BERA Steps 4 and 5 at Hunters Point Shipyard, CA. Immunoassay results for PCBs (left) and XRF results for Cu (right) are shown.

results can be used to delineate boundaries of impacted areas to ensure each potential source is sampled and laboratory data will be available to estimate relative source contributions to Navy sediments. As is often the case in sediment assessments, multiple potential sources are present. These sources need to be considered in the design of a sampling plan for the baseline assessment.

Evaluation of Remedial Alternatives

The purpose of this step is to ensure that remedial alternatives are adequately evaluated from an ecological perspective, so that the outcome of the remediation is not more detrimental to the environment than if the site had not been remediated [6]. Rapid characterization tools can play a role in this tier as well. If a remedial option is selected, costs are critically dependent on volumes or areas to be managed. Rapid characterization can be used to map out areas or volumes at higher density than were used for the assessment. Rapid characterization can also be used to verify the efficacy or completeness of a remedial option such as containment, cap or remove impacted sediments, and monitor the long-term efficacy and impact of management strategies.

CONCLUSIONS

A few important points must be considered in the selection and application of RSC tools to the ERA process. First, it is important that site-specific project goals and parameters as defined by the DQO Process must be considered. It is critical to ensure that the contaminants or criteria that are deemed to be decision drivers are detectable with the RSC tools that are available. Also, as with any method or technology, certain limitations exist. The primary limitations to RSC technologies are that they are often (1) non-specific, (2) semi-quantitative, and (3) matrix-sensitive. Because of these limitations, the data produced by RSC tools/methods are not necessarily equivalent to those generated by standard methods. Depending on the data quality requirements established during the DQO Process, a well-designed RSC protocol, paired with laboratory validation, will be able to provide data that can be of sufficient quality and great value to the risk assessment. It is important to note that results can be misleading if non-equivalent data are combined without careful intercalibration. A few different approaches to the documentation and reporting of data can be used to avoid such problems when reporting results, particularly those from RSC methods. The first reporting approach is to always flag numbers generated by a non-standard method in spreadsheets and data reports, and to include text, references, or qualifiers that address any potential offsets from standard analyses. A second approach is to carry out site-specific calibration of RSC analyses and to report only corrected, calibrated data. A third option, particularly for RSC analyses that generate only qualitative data (i.e., data that identify the presence or absence of target analytes, but may have no relationship to true concentrations of the analytes) is not to report numerical values, but instead report qualitative values (e.g., non-detect, etc). Samples are either ranked or ranges are reported. Finally, a concern voiced by many potential users of RSC tools is that, since they are not subject to the same quality assurance/quality control (QA/QC) protocols and rigors as are standard procedures, they will make the user vulnerable by not standing up to regulatory or legal scrutiny. While these concerns are not trivial, it is clear that there are a growing number of case studies in which remedial project managers, regulators, and the user community have accepted RSC data as a critical, though not stand-alone, part of the analytical and decision-making process. In any case, the intent to use RSC tools, and how the resulting data will be interpreted and managed, should be addressed up front with regulators and other stakeholders.

Implementation of rapid characterization tools in ecological risk assessments will improve sampling and reduce uncertainty at several steps of the remedial investigation/feasibility study process without the enormous cost of traditional resampling efforts. Use of these tools moves the ERA process forward in the most time- and cost-effective manner with minimum uncertainty.

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LIST OF TRADEMARKS

AFTERWORD

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